GEOLOGY OF THE MOUNTAIN UPLIFT TRANSECTED BY THE SHOSHONE CANYON, WYOMING

A DISSERTATION SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

By

GEORGE DUNCAN JOHNSON

1934

Reprinted for private circulation from
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VITA

George Duncan Johnson was born in Roland Park, Maryland, on November 17, 1907. His elementary education was, for the most part, in the public schools of Baltimore. He pursued his high school studies for three years at the Baltimore City College and was graduated in June, 1924. During the academic year 1924–25 he attended courses in science and French language at the Université and Collège of Geneva, Switzerland.

In October, 1925, he entered Johns Hopkins University as an undergraduate, and three years later first entered upon the study of Geology. For five years he pursued this study under the instruction of Professors H. F. Reid, C. K. Swartz, E. B. Mathews, E. W. Berry, J. T. Singewald, Jr., Ernst Cloos, and C. W. Kockel.

For two field seasons of four months he was employed with parties of the U. S. Geological Survey in the northwestern states; in 1929 with Dr. Wm. C. Alden in physiographic reconnaissance; and in 1930 with J. T. Pardee and P. J. Shenon in a study of various metalliferous deposits. During two months of 1931 and four months of 1932 he carried on geologic studies in northwest Wyoming, the results of which were presented in the accompanying dissertation. In June and July, 1926, he accompanied a botanical expedition to Jamaica. Opportunity was afforded in 1930 and 1933 to visit mining districts of the southeastern states; in 1931 to visit the mines of the east-central states; and in 1926–30–31–32 to visit many points of geologic and scenic interest in the western United States.

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GEOLOGY OF THE MOUNTAIN UPLIFT TRANSECTED BY THE SHOSHONE CANYON, WYOMING[1]

G. DUNCAN JOHNSON
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ABSTRACT

The region of Shoshone Canyon is significant, because it contains both overthrust and block-faulted structures in close association. The stratigraphic section comprises 3,200 feet of conformable, marine, Paleozoic sediments, 800 feet of Permo-Triassic red beds and over 5,000 feet of Jurassic and Cretaceous sandstones and shales. This is notably thinner than the corresponding section in the overthrust belt of southeastern Idaho, but greater than that in the front ranges of Wyoming and Colorado.

Flexures, which appear as folds in the Paleozoic and Mesozoic strata, have been traced with certainty to sharply faulted blocks of the underlying pre-Cambrian complex. Distinct from these is the Heart Mountain overthrust which places Paleozoic limestones above sediments of Mesozoic and early Tertiary age. The two types of structure are shown to differ in age and in the thickness of rocks involved. Upfaulting of the pre-Cambrian with flexing of the sediments took place in late Upper Cretaceous. These uplifts were extensively eroded and covered with sands and gravels before the overthrusting in late Eocene or Oligocene. Further faulting in Miocene and later time accentuated the earlier uplifts and disposed the remnants of the overthrust sheet at four different elevations.

INTRODUCTION

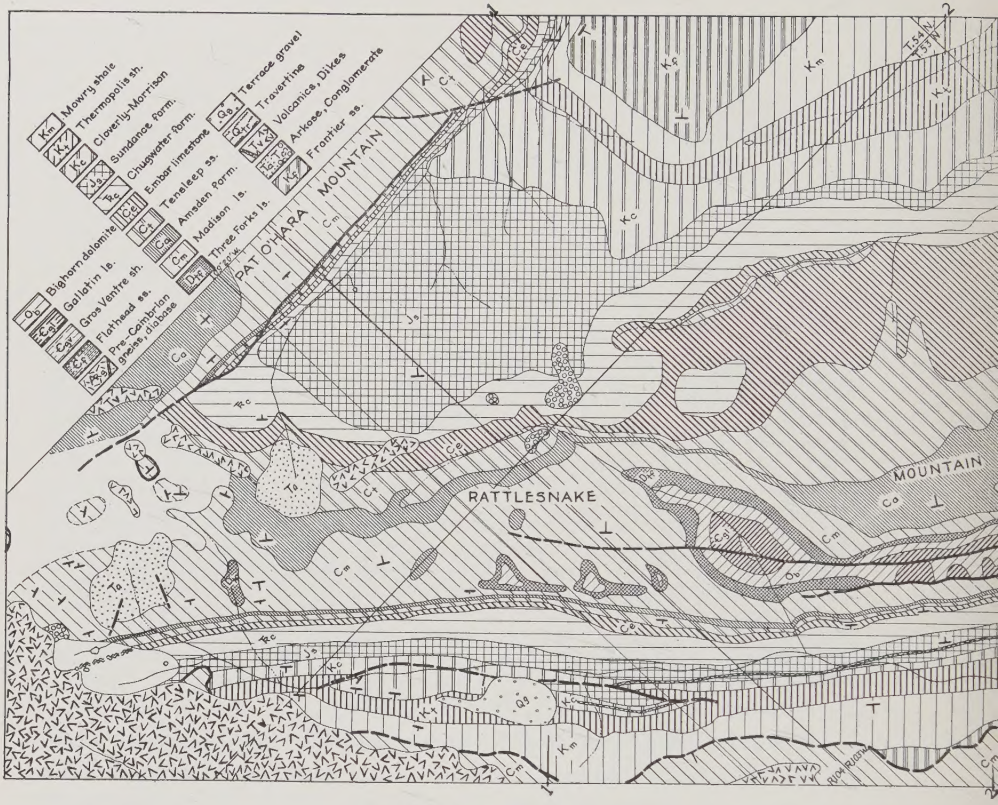
West of the Bighorn Basin in northwestern Wyoming lie the mass of volcanic flows and agglomerates of the Absaroka Range and the southern tip of the uplifted pre-Cambrian block of the Beartooth Mountains. At the margin of the Basin, as a southward physiographic continuation of the Beartooth front, is a series of mountain ridges in which pre-Cretaceous strata are uplifted (Fig. 2). The longest and southernmost of these comprises Rattlesnake and Cedar mountains, between which the Shoshone River has cut a canyon 3,000 feet deep, just west of the town of Cody (Fig. 3).

With the exception of a rough reconnaissance by T. B. Comstock in 1873, Eldridge,[2] of the U.S. Geological Survey, was the first to describe the geology of the region. Not until the work of Dake[3] were

[1] Doctor's Dissertation presented at Johns Hopkins University, February, 1934.

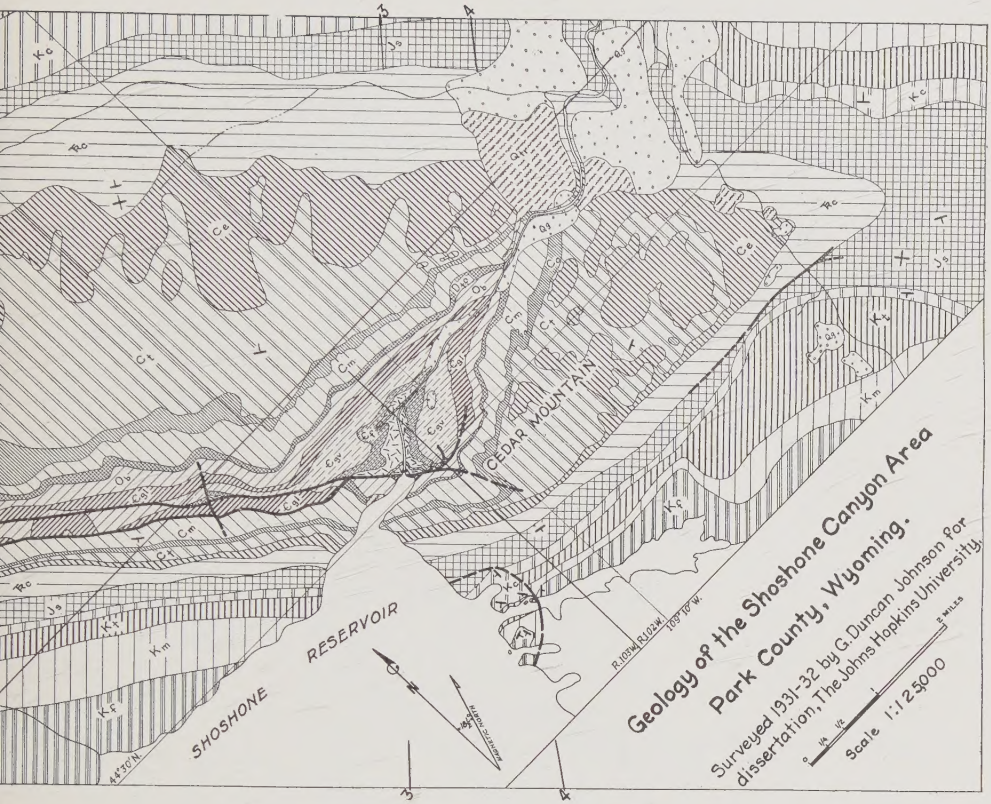
[2] George H. Eldridge, "A Geological Reconnaissance of Northwest Wyoming," *U.S. Geol. Surv., Bull. 119* (1894), pp. 29–32.

[3] C. L. Dake, "The Heart Mountain Overthrust and Associated Structures in Park County, Wyoming," *Jour. Geol.*, Vol. XXVI (1918), pp. 45–55.



Note.—*Vertic*

FIG. 1.—Geologic



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4

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the segments of the Heart Mountain overthrust correctly interpreted. There still remained the difficulty in explaining the relation of

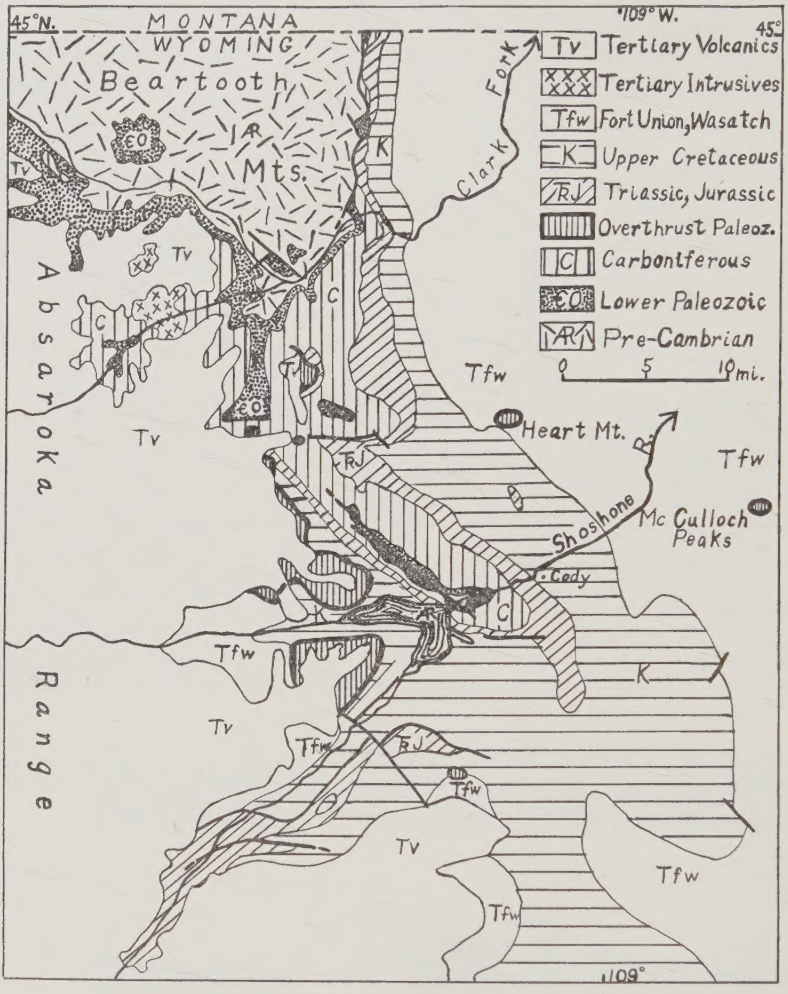
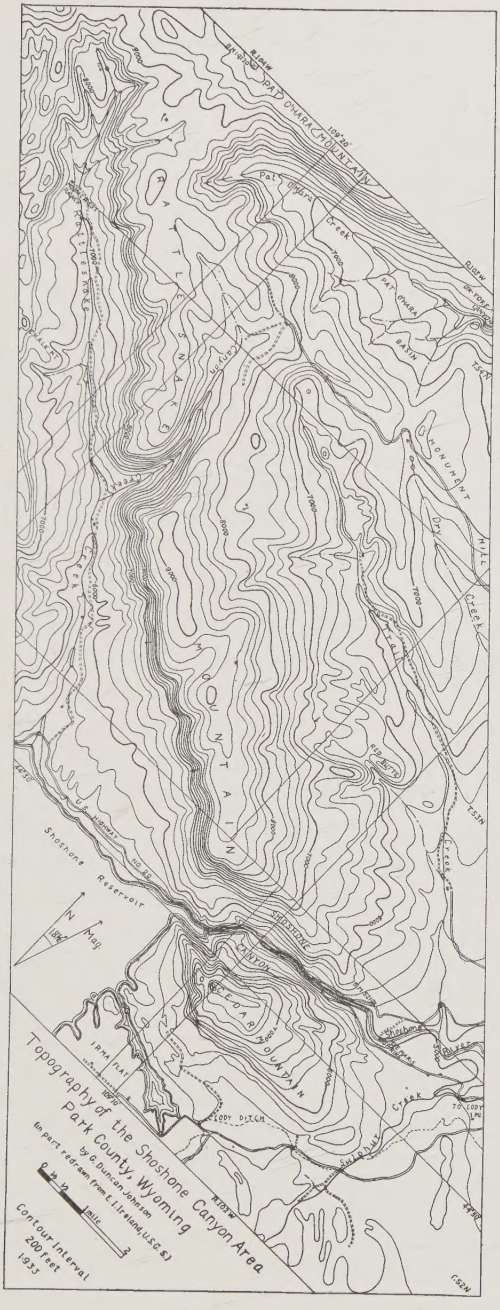


FIG. 2.—Regional geologic map to show relation of Heart Mountain overthrust and uplifts (geology of Beartooth Mountain front from R. V. Hughes. *Proc. Nat. Acad. Sci.*, Vol. XIX [1933], Fig. 1).

the "asymmetric anticline" of Rattlesnake Mountain to the overthrust. It was toward a solution of this problem that the present investigation was undertaken.


Topography of the Shoshone Canyon Area
Park County, Wyoming
by O. Duncan Johnson
In part redrawn from U.S. Forest Map
Contour Interval
200 feet
1935
Shoshone Reservoir
Rattlesnake Mountain
Cedar Mountain
Sheridan Creek
Eocene Creek
Cedar Creek
Eocene Ditch
Cody Ditch
Cody Canyon
Sheridan Canyon
Monument Hill
Monument Day
Sheridan Ridge
Sheridan Trail
Sheridan Pass
Rattlesnake Pass
Rattlesnake Trail
Rattlesnake Ridge
Rattlesnake Creek
Rattlesnake Basin
Rattlesnake Divide
Rattlesnake Mountain

Field studies of Rattlesnake–Cedar Mountain, together with the adjacent valleys and part of Pat O'Hara Mountain, were carried out in August and September, 1931, and June to September, 1932. The Princeton University Geological Research Base, under the direction of Professor W. Taylor Thom, Jr., facilitated the work by the loan of field equipment and by putting the writer in close touch with other geologists working in the region.[4]

STRATIGRAPHY AND PETROLOGY

The stratigraphic section exposed in Shoshone Canyon and in the river trench below the Canyon represents an essentially conformable though discontinuous sequence from the Middle Cambrian through the Upper Cretaceous (Fig. 4). Overlying this series with pronounced unconformity are conglomerates, arkoses, and basic volcanics of Tertiary age, and terrace gravels and travertine probably no older than Quaternary.

The Paleozoic marine series consists roughly of 60 per cent limestones and dolomites, 25 per cent shales, and 15 per cent sandstones. Most investigators of the region agree that no rocks are present to represent the Algonkian, Lower Cambrian, Lower Ordovician, Silurian, or Lower Devonian. Formation names and boundaries have been adopted from descriptions by Darton, Tomlinson, Blackwelder, and Lovering[5] with little regard for the earlier division in the Yellowstone Park region.

Flathead sandstone (Middle Cambrian).—The Flathead sandstone lies on the nearly plane surface of the pre-Cambrian granite and out-

[4] To A. N. Dusenbury, Jr., Freeman Foote, T. J. Gillen, Jr., and Carl Broedel, the writer owes a debt of thanks for their services as field assistants. Howard Bell, Edward Heald, Willard Rhodes, Mr. and Mrs. Elmon Hall, and George Cless, residents of Park County, were especially helpful during the progress of the field work. A small contribution by the Cody Club toward field expenses is gratefully acknowledged. Professor Ernst Cloos, of Johns Hopkins University, has given much helpful advice.

[5] N. H. Darton, "Geology of the Bighorn Mountains," *U.S. Geol. Surv. Prof. Paper 51* (1906); "Geology of the Owl Creek Mountains," *59th Cong. 1st Ses. Senate Exec. Doc. 219* (1906); C. W. Tomlinson, "Middle Paleozoic Stratigraphy of the Central Rocky Mountain Region," *Jour. Geol.*, Vol. XXV (1917), pp. 112–34, 244–57, 373–94; Eliot Blackwelder, "New Geologic Formations in Western Wyoming," *Jour. Wash. Acad. Sci.*, Vol. VIII (1918), pp. 417–26; T. S. Lovering, "The New World or Cooke City Mining District, Park County, Montana," *U.S. Geol. Surv. Bull. 811(a)* (1929), pp. 17–29.

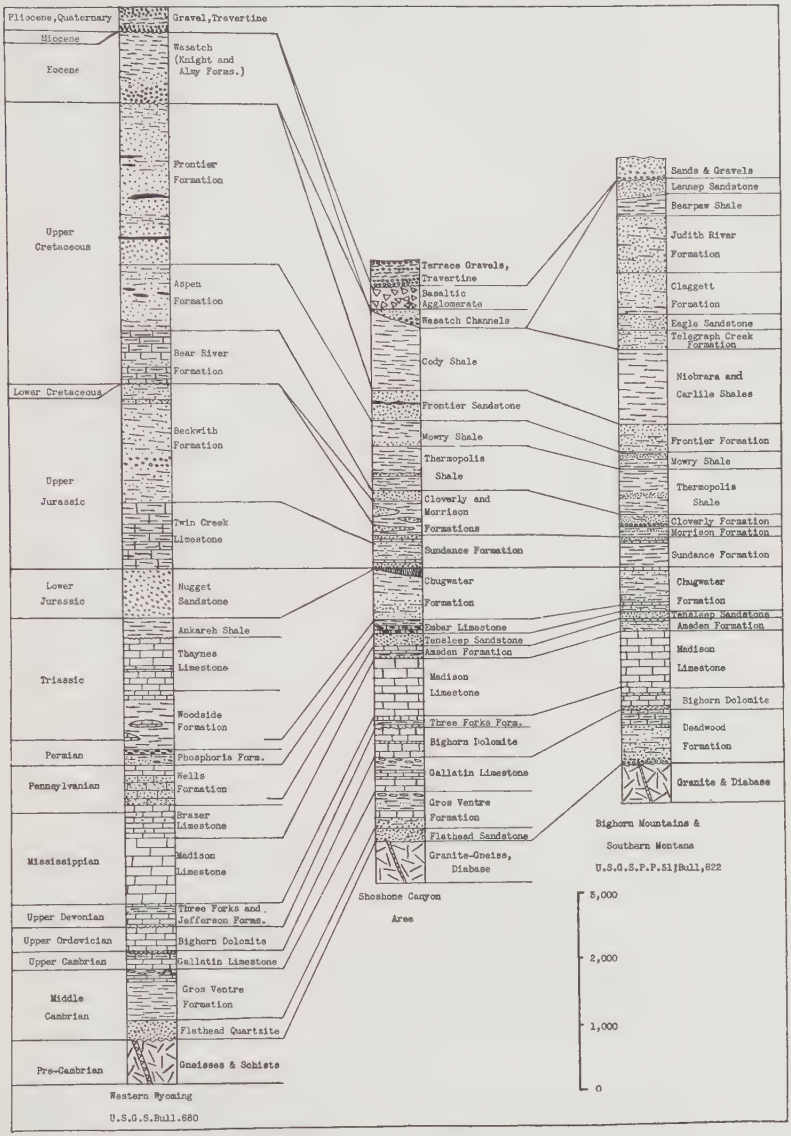


FIG. 4.—Stratigraphic column correlated with regions to the west and east

crops as a fringe along the walls of the inner gorge of Shoshone Canyon. It is a brownish, indurated sandstone or quartzite with lenses of very coarse sandstone or fine quartz conglomerate in the lower 20 feet. No persistent basal conglomerate overlies the pre-Cambrian surface. On the high bench southeast of Shoshone dam the Flathead section is:

	Feet
Sandy oölitic hematite with "*Lingulella*"	5
Medium-bedded, brown-spotted sandstone	20
Massive, medium-grained, brownish sandstone	120
	145

Gros Ventre formation (*Middle Cambrian*).—The Gros Ventre formation is composed largely of shales and thin-bedded sandstones, but certain hard beds outcrop conspicuously. The section on the south side of Shoshone Canyon is:

	Feet
Greenish limy and sandy shales; flat-pebble conglomerates	200
Hard, maroon sandstone	8
Thin-bedded sandstones and sandy shales	180
Nodular limestone with shaly beds	95
Brown, lime-cemented sandstones; limy shales	90
	573

Gallatin limestone (*Upper Cambrian*).—A massive, cliff-forming limestone, thin-bedded limestones, and flat-pebble limestone conglomerates have been grouped as the Gallatin formation. Exposures on the north side of Shoshone Canyon show:

	Feet
Flat-pebble conglomerates; shales, with trilobite fragments	200
Massive bed of limestone	12
Thin-bedded limestones; calcareous shales	120
Cliff-forming, dolomitic limestone, some nodular beds	180
	512

Flat-pebble limestone conglomerates occur in the upper Gros Ventre but are especially characteristic of the Gallatin. Ellipsoidal pebbles, 1–5 inches in diameter and $\frac{1}{4}$–1 inch thick, lie usually parallel to the bedding or occasionally at steep angles to it. A greenish-yellow calcareous shale binds the pebbles together and constitutes intervening layers free from pebbles. That these are typical intraformational

conglomerates is demonstrated by their repeated recurrence, and the presence exclusively of flat pebbles of soft limestone derived from underlying beds.

All the Cambrian beds described had been embraced in the Deadwood formation by Darton in the Bighorn Mountains. Only in regions farther west have subdivisions of the Cambrian been made. The distinctive lithologic characters, however, are sufficiently well marked to make such a division possible in the Shoshone Canyon.

Bighorn dolomite (Upper Ordovician).—All of the cliff-forming dolomites between the flat-pebble conglomerates of the Gallatin and the soft, orange limestones of the Three Forks are mapped as Bighorn dolomite. Stadia measurements of a high bluff on the north side of the Canyon west of the highway bridge give:

	Feet
Hard, silicious dolomite, usually brecciated	20
Massive, buff dolomite	125
Fine-grained, white dolomite weathering chalky	5
Massive dolomite; thin beds of sandstone	18
White, chalky dolomite	17
Massive, gray dolomite	10
White, closely-fractured dolomite	60
Light buff, massive dolomite	85
Buff and gray massive dolomite	110
	450

A fossiliferous basal sandstone (Lander sandstone) appears to be lacking in the Shoshone Canyon section. Approximately at the top of the Bighorn is a single occurrence of reddish limestone. This lenticular body yielded no fossils, but probably can be interpreted as an early Devonian filling of a channel in the Bighorn, like those described by Hughes[6] as "basal Jefferson" along the Beartooth Mountain front.

Three Forks formation (Upper Devonian).—Overlying the Bighorn with few evidences of unconformity is a group of soft, orange-buff limestones and yellow-green shales which are correlated solely on the basis of lithology with the Three Forks formation as described by

[6] R. V. Hughes, "The Geology of the Beartooth Mountain Front in Park County, Wyoming," *Proc. Nat. Acad. Sci.*, Vol. XIX (1933), pp. 239–53.

Tomlinson and Lovering.[7] Beds of shale and limestone with a few thin sandstones alternate to give a total thickness of 180 feet. Possibly the upper 40 feet of the measured Bighorn section, together with 80 feet of beds with typical Three Forks lithology, represent a diminished thickness of the Devonian Jefferson dolomite.

Madison limestone (*Mississippian*).—Following directly upon the Three Forks is the great thickness of Madison limestone. This is by far the most conspicuous formation in the area, forming two distinct series of cliffs on either side of Shoshone Canyon and a remarkable line of palisades above Rattlesnake Valley (Fig. 7). Wherever remnants of the Heart Mountain overthrust occur, Madison limestone forms a conspicuous cliff. The entire thickness of the Madison shows little variation in general character; such features as lenses of coral-reef limestone, brecciation, and solution cavities are irregularly distributed from bottom to top. No persistent fossil horizons could be distinguished, although the formation as a whole is noticeably fossiliferous. Because of the lack of key beds and the secondary brecciation of much of the Madison section, the measured thickness of 900 feet is at best an approximation.

Amsden formation (*Pennsylvanian*).—The soft limestones of the Amsden formation are usually concealed beneath a mantle of reddish soil. Only the basal quartzite is conspicuous as a capping of the highest crest of Rattlesnake and Pat O'Hara mountains. A composite section from the north side of Shoshone Canyon is:

	Feet
Blue chert	1
Cross-bedded, brown sandstone	10
Sandy limestone with chert	15
Red-purple sandstone	6
Soft, buff to pink limestone	60
Thin-bedded purplish limestone and shale	70
Cross-bedded indurated sandstone	0–10
	172

Tensleep sandstone (*Pennsylvanian*).—Because of its great resistance to weathering, the Tensleep sandstone occupies a conspicuous place in the areal geology. An additional area is covered by broken blocks of sandstone to such a depth that the talus might well be con-

[7] *Op. cit.*, pp. 124, 383–85; *op. cit.*, p. 28.

sidered a geologic unit in itself. The Tensleep in place comprises 180 feet of massive, usually cross-bedded sandstone, white on a fresh break but weathering to a characteristic reddish-brown. With the Tensleep the uniform marine sedimentation over a large region during the Paleozoic came to an end.

Embar limestone (*Permian*).—The term "Embar" has been retained to designate a series of shaly and cherty limestones which represent the extension into northern Wyoming of the Phosphoria, Dinwoody, and part of the Park City formations of western Wyoming and southeastern Idaho. The extreme variation in thickness and facies of the Embar and its equivalents is discussed by Condit,[8] who shows that the phosphatic limestone facies of the Wind River Mountains becomes thinner toward the east and intertongues with red bed facies. On the slopes of Cedar Mountain the Embar includes:

	Feet
Yellowish-calcareous shales	30
Nodular limestone	10
Red sandstone	4
Yellow-green, shaly limestone	50
Platy, sandy limestone	27
Sandy limestone with few chert nodules	30
Thin-bedded limestone (chert and lime concretions)	15
Brown, massive limestone (chert and calcite vugs)	18
Yellow, sandy limestone	16
Nodules of chert cemented by lime	10
	210

Chugwater formation (*Permo-Triassic*).—Red beds of the Chugwater formation are typically developed around the Rattlesnake Mountain uplift. The general succession is:

	Feet
White, saccharoidal and massive gypsum	0–90
Red shales with seams and flakes of gypsum; interbedded red sandstones toward base	410
Interbedded red sandstones and shales, with a few yellow sandstone beds	300
	800

[8] D. D. Condit, "Relation of the Embar and Chugwater Formations in Central Wyoming," *U.S. Geol. Surv. Prof. Paper 98 (o)*, (1917).

Extreme local variations in thickness, especially of the gypsum member of the Chugwater, are only in part the result of unconformities. Condit[9] has suggested that thinning may result from solution of gypsum or other salines. Along the sharp flexures of Rattlesnake and Pat O'Hara mountains the gypsum and a large part of the shales appear to have been squeezed out during deformation. Neither the "red bed conglomerates," nor the Alcova limestone, nor the fossiliferous Popo Agie facies has been found in the Cody region; consequently the Permian, the Triassic, and the Jurassic portions of the red beds cannot be distinguished.

The stratigraphic section from the base of the Sundance to the Eocene Wasatch beds has been described in sufficient detail by Hewett.[10] Only slight changes have been made in the grouping of the units described into formations.

Sundance formation (Jurassic.)—A summary of the Sundance section measured by Woodruff and Hewett along Shoshone River is:

	Feet
Cross-bedded, massive sandstone; thin beds of limestone	66
Greenish shale, sandy and glauconitic; belemnites and *Gryphaea*	300
Reddish shale with veinlets of gypsum	50
Granular to massive white gypsum	12
Fossiliferous limestone; interbedded shales	60
Fossiliferous sandstone	5
	493

Morrison and Cloverly formations (Lower and Upper [?] Cretaceous).—The separation of Morrison and Cloverly formations in Wyoming has customarily been made on the basis of a conspicuous conglomerate bed between two zones of varicolored shales. No such conglomerate occurs in the Shoshone River section; consequently Hewett includes all of the shales in the Morrison and leaves for the Cloverly only the rusty sandstones of the Greybull member. The writer, in mapping the Morrison and Cloverly in the Shoshone Canyon area, early concluded that no reliable criterion exists for differentiating the two formations. White sandstones in the Morrison are seen to lens out and be replaced by others at higher or lower horizons. A con-

[9] *Ibid.*, p. 268.

[10] D. F. Hewett, "The Shoshone River Section, Wyoming," *U.S. Geol. Surv. Bull. 541 (c)*, (1912).

glomerate character may appear in any one of these lenses and by no means marks a fixed horizon. The combined formations may be described in three groups:

	Feet
Buff sandstone, thin-bedded to massive (Greybull member)	110
Varicolored clays with many sandstone lenses	440
Green, sandy shales	180
	730

Thermopolis shale (*Upper Cretaceous*).—Following directly upon the Greybull sandstone are black shales of the Colorado group. That part which is known in the Bighorn Basin as Thermopolis shale consists of:

	Feet
Dark-gray, dense shale	50
Massive white sandstone	5
Black shale; thin beds of bentonite	390
Massive sandstone ("Muddy Sandstone")	20
Black shale	185
	650

Mowry shale (*Upper Cretaceous*).—The succeeding 375 feet of hard sandy shales in the Shoshone River section constitute the Mowry Formation.

Frontier sandstone (*Upper Cretaceous*).—The middle sandstone member of the Colorado group is known throughout northwestern Wyoming as the Frontier sandstone and is equivalent to the Torchlight sandstone of Montana. On Shoshone River it has a thickness of 495 feet.

Late Upper Cretaceous and early Tertiary formations.—No Cretaceous strata higher than the Frontier sandstone enter into the structural relations to be described, but they will be mentioned briefly to indicate the amount of post-Cretaceous erosion. The following formations are now recognized for the Cody region:

	Feet
Fort Union formation (Paleocene)	5,600
Lance formation (Paleocene)	1,800
Meeteetse formation (Upper Montana)	900
Mesaverde formation (Lower Montana)	1,200
Cody shale (Upper Colorado)	1,800
	11,300

Tertiary Channel deposits (Eocene ?).—Entirely distinct from the great series of strata which have been described are patches of arkose and conglomerate alined across the north end of Rattlesnake Mountain. These rest unconformably upon beveled Pennsylvanian and Permian strata. Granite, quartzite, and limestone boulders from the conglomerate are enveloped in the base of basalt flows at the head of Rattlesnake Valley. Thus the conglomerates are later than the first mountain uplift and earlier than the Miocene volcanics. From the arkoses, Dorf[11] has collected plants found in the typical Bighorn basin Wasatch beds. A reasonable interpretation is that these coarse materials mark a channel through which sediments were carried from mountain uplifts farther west and northwest to the basin of Wasatch deposition. Hence they represent a border phase of the Wasatch formation of Eocene age.

Terrace gravels and travertines in the vicinity of Cody have been well described by Fisher.[12]

Petrology of the pre-Cambrian.—Four distinct rock types are represented in the pre-Cambrian complex exposed in the Shoshone Canyon. In the probable order of age they are: hornblende-chlorite schist; quartz-diorite, granite-pegmatite, and diabase. The first three are intimately associated to form one gneissic complex, whereas the diabase cuts the latter with sharp contacts. Attenuated lenses and stringers of schist consist of hornblende, chlorite, quartz, and a little andesine. Absence of albite, biotite, or sericite suggests that these bodies represent xenolithic inclusions of an early paraschist.

Quartz diorite, constituting the main mass of the pre-Cambrian, consists essentially of quartz, oligoclase, and greenish biotite. Much of the diorite has been permeated by pegmatitic solutions which introduced microcline and additional quartz. Thick layers of granite pegmatite are emplaced along flat joints in the quartz diorite. Pure bodies of the pegmatite consist of pink microcline, quartz, and "nests" of mica.

Diabase dikes and sills intrude along joint planes of the gneissic complex. One immense dike in the bed of Shoshone River is over

[11] Erling Dorf, verbal communication.

[12] C. A. Fisher, "Geology and Water Resources of the Bighorn Basin," *U.S. Geol. Surv. Prof. Paper 53* (1907), pp. 34, 61, Pl. XVI.

100 feet thick and surrounds a large xenolithic body of granite. Petrographically it is an augite-diabase with a little quartz, resembling those common to all exposures of pre-Cambrian in Wyoming.

Tertiary igneous rocks (Miocene).—Flows and agglomerates of pyroxene-andesite extend across the head of Rattlesnake Valley onto Pat O'Hara Mountain. They represent a common type of the early basic volcanics of the Absaroka Range described by Iddings.[13] Two large dikes of andesite-porphyry parallel the west side of Rattlesnake Mountain and a third was discovered cutting the Cretaceous south of Ox Yoke Canyon. The fissure lines marked by these dikes show a close relation to the mountain deformation.

STRUCTURE

Faulting, flexing, and overthrusting of latest Cretaceous and early Tertiary age have produced the major structural features of the Shoshone Canyon area. In addition to these, there are indications of tectonic disturbances in the pre-Cambrian rocks alone, and of late Tertiary or Recent adjustments by faulting. These features will be interpreted in order of age rather than of importance.

Pre-Cambrian jointing.—The well-developed joints in the gneissic complex of Shoshone Canyon may be grouped with few exceptions into three systems: N. 5° E., δ 75° W.; N. 10° E.; and N. 90° E., δ 85° S. The flat-lying joints clearly were developed before or during the intrusion of the granite-pegmatites, and the steeper systems before the pre-Cambrian diabase. It is interesting to note that were the pre-Cambrian peneplained surface restored to a horizontal position by rotation about a N. 50° W. axis two of the joint systems would become vertical and the third nearly horizontal. The remaining joints in the pre-Cambrian are grouped adjacent and parallel to the fault plane west of Shoshone dam. This fault is of late Cretaceous age and it is reasonable to assume that the closely associated joints were contemporaneous.

Two significant deductions are possible. (1) During pre-Cambrian time orogenic forces produced systems of latitudinal, meridional, and horizontal joints followed by intrusions of pegmatite and dia-

[13] J. P. Iddings, "The Igneous Rocks of the Absaroka Range, etc.," *U.S. Geol. Surv. Mon. XXXII*, Pt. II (1899), pp. 275–96.

base. (2) When the next great orogenic cycle affected the region in late Cretaceous time the prevailing directions of faulting and jointing were at an angle of approximately 45° to those of the pre-Cambrian.

No evidence of orogenic activity in Paleozoic or early Mesozoic time has been discovered in western Wyoming. To be sure, numerous epeirogenic movements must be called into play to account for the several hiatuses and disconformities within the stratigraphic series.

LARAMIDE STRUCTURES

All the important faults and overthrusts of the Middle Rocky Mountain region were developed during one or more stages of post-Cretaceous or Laramide orogeny. To which stage the several events in each locality should be assigned is seldom certain and the exact geologic dating of any stage is usually not possible. Five stages are suggested by Hewett[14] for the west side of the Bighorn basin. Four recognized in the Shoshone Canyon area are: (1) pre-Wasatch faulting and "folding," (2) late Eocene overthrusting, (3) latest Eocene faulting, and (4) post-Miocene faulting.

Normal faults and flexures of Rattlesnake–Cedar Mountain.—The deep incision of Shoshone River reveals beyond any doubt the nature of the Rattlesnake–Cedar Mountain uplift. Pre-Cambrian granite is brought into contact with southwestwardly dipping beds of Ordovician dolomite by a steep normal fault. (Fig. 1, Sec. 3; Fig. 5). Erosion has nowhere reached pre-Cambrian rocks on the southwest side of the fault; hence, neither the exact displacement of the pre-Cambrian erosion surface nor the dip of this surface to the west can be observed. The displacement of the surface of the granite is probably greater than the 2,200 feet maximum displacement of the Bighorn dolomite; possible more than 3,000 feet.

Both northwest and southeast of the river the mountains rise rapidly, so that the fault trace passes entirely within the Paleozoic strata. The displacement is distributed among several branches of the fault on the north flank of Cedar Mountain, and is so largely taken up by yielding of the Lower Paleozoic sediments that Madison

[14] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *Jour. Geol.*, Vol. XXVIII (1920), table facing p. 556.

limestone shows a nearly unbroken flexure below the mountain crest (Fig. 1, Sec. 4). In Cedar Mountain the uptilted mountain block terminates. Around the dip-slope of this mountain the strike of the Tensleep sandstone undergoes a change of 180°, of which 60° occurs abruptly at the southwest angle. The Embar and Chugwater formations likewise encircle Cedar Mountain as the uplift plunges to the southeast.

Half a mile northwest of the river, the great fault splits into two, which continue parallel for 7 miles along the face of Rattlesnake

FIG. 5.—Displacement of Rattlesnake Mountain fault at Shoshone dam. Looking northwest from Cedar Mountain (cf. Fig. 1, cross section 3).

Mountain. Displacement by the inner or northeastern of the two faults becomes less than 1,000 feet, and that by the outer fault is greater but difficult to estimate, since it so closely parallels the bedding. The fault trace across gulches and spurs shows that the outer fault dips less steeply than the inner one; hence the two planes probably do not converge in depth. The tripartite structure is well exhibited in each transverse gulch (Fig. 1, Sec. 2; Fig. 6). The uptilted mountain block shows uniform northeast dips and rises in steplike cliffs which have weathered back from the fault plane. The median structural block, between the two fault planes, appears as a segment of a flat arch, the beds dipping gently toward each fault. Strata of the downthrow block dip 45°–90° to the west along the mountain

front but rapidly flatten out under Rattlesnake Creek Valley. Overturning of the beds, depicted in cross section 2, is restricted to less than 2 miles of the mountain front.

The aspect of the west side of Rattlesnake Mountain undergoes a distinct change beyond the deep gorge of Canyon Creek. The outer of the two parallel faults no longer reaches the surface, but in line of its projection is a right-angle flexure in the Madison limestone. In gulches erosion has cut to the upper beds of the Bighorn dolomite and on the spurs part of the fractured Madison limestone has been

FIG. 6.—Tripartite structure of Rattlesnake Mountain, 3 miles northwest of Shoshone dam. Looking southeast (cf. Fig. 1, cross section 2).

removed along the axis of the flexure. The resulting topographic expression is a series of palisades of vertical Madison limestone and a cliff marking the edge of the same beds in a horizontal position east of the flexure (Fig. 1, Sec. 1; Fig. 7). A second less pronounced cliff farther east indicates that the inner fault continues northwestward with diminishing displacement at the surface. As the land rises toward the head of Rattlesnake Creek, the depth to which the structure is exposed decreases. The steep west limb and flat east limb of the Rattlesnake Mountain flexure, however, can be traced practically to the edge of the volcanic cover.

The northeast slope of Rattlesnake Mountain is not precisely a uniformly dipping structural plane. Flat dips along the crest in-

crease eastward to a maximum of 20°, then flatten and steepen again to form a structural bench at an elevation of about 6,500 feet. Farther northeast the dip decreases to a gentle syncline. A few small, transverse elements were observed in the mountain structure. A small outcrop of pre-Cambrian attracted attention to a fault of about 150 feet displacement, northwest of Shoshone Canyon. Evidence of a fault of the same sort in the bed of Canyon Creek is not conclusive. Near the head of Trail Creek a small syncline, transverse to the general strike, causes the outcrops to be deflected.

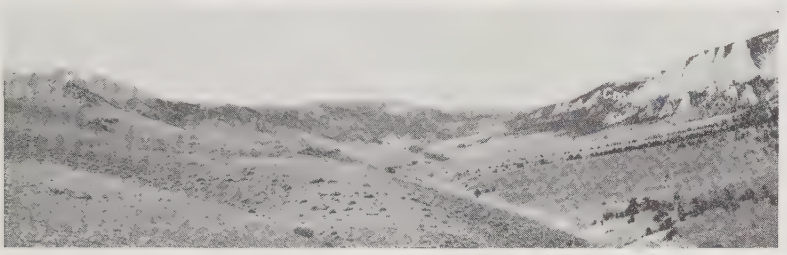


FIG. 7.—View northwest to head of Rattlesnake Creek. Overthrust Madison limestone of Chalk Mountain (left). Relatively displaced remnants of overthrust (center). Vertical and horizontal Madison of Rattlesnake Mountain (right) (cf. Fig. 1, cross section 1).

A flat uplift in the Mesozoic strata, southeast of Cedar Mountain, would appear to be related to the Rattlesnake Mountain structure. The two structural axes, however, differ in strike by nearly 45°. Although the east limbs of the structures are continuous from one to the other, the hogback ridges southwest of Cedar Mountain are offset 3 miles to the east by two sharp bends and a strike fault. The strata rise in steep hogback ridges on either side of the structure, connected by a very flat arch, slightly depressed at the crest.

Pat O'Hara Mountain uplift.—Pat O'Hara Mountain is a structural unit distinct from the Rattlesnake–Cedar Mountain uplift. Its east-west axis diverges at 45° from the north end of Rattlesnake Mountain. It is a similar uptilted block with a steep fault on its south flank and moderate dips northward from the crest. The gentle dip slope of Rattlesnake Mountain continues northwestward to within less than a thousand feet of the east-west strikes of Pat O'Hara Mountain. Embar and lower Chugwater beds abut on the Pat

O'Hara fault, whereas the upper Chugwater, Sundance, and Cloverly turn sharply through an angle of 120° to continue with vertical dips parallel to the Pat O'Hara axis. Thus there is produced between the two mountain uplifts an asymmetric syncline with the axis pitching S. 80° E.

On Pat O'Hara Mountain the fault which reaches the surface is well below the crest of the uplift. Its stratigraphic throw is small, compared to the displacement of over 1,000 feet, since it parallels the strike and dip of the beds. The fault passes to the east into a mass of landslide débris where it probably terminates against a cross fault. Toward the west the Pat O'Hara fault is last evident where Madison limestone is brought in contact with Chugwater sandstones. Beyond that point the intersection of the Rattlesnake and Pat O'Hara Mountain structures is obscured by volcanic rocks and their débris, as well as by soil cover on the flat upland. Scattered outcrops show strikes and dips discordant with either of the mountain structures, or show intense crushing which has obliterated the bedding. The most conspicuous of these isolated outcrops shows a definite east-west strike and dip of 45° to the north.

Heart Mountain overthrust.—Along the west edge of Rattlesnake Creek Valley are cliffs of Paleozoic limestone which are known to be part of the Heart Mountain overthrust sheet. That part of the thrust plane shown in Figure 1 is everywhere covered by talus, but its approximate trace indicates a nearly horizontal dip. Generally the limestone of the overthrust block is fractured and its dip, where discernible, is irregular in direction but nowhere steep. Frontier and Mowry beds underlie most of the overthrust west of Rattlesnake Creek, but a small segment near the head of the creek is definitely in contact with Cloverly and Sundance. Large blocks of the limestone appear to have moved down the slope by creep, especially at the township line 52N.–53N.

All known or probable remnants of the overthrust sheet are shown in Figure 2, and in Figure 7 the relation of overthrust Madison limestone to the same beds involved in the Rattlesnake Mountain structure is clearly shown. In the original map of the overthrust Dake[15] shows secondary thrust faults beneath the principal plane. None of

[15] *Op. cit.*, p. 48.

these is within the bounds of the present map, but structures believed to be similar are shown southwest of Cedar Mountain and in the upper Rattlesnake Valley.

INTERPRETATION OF STRUCTURE

Block uplifts.—The essential feature of the Rattlesnake–Cedar Mountain uplift is apparent from a geologic map and cross sections. Uplift and tilting of one large block of basement complex are fundamental, and to these flexing and minor faulting are sequential. To account for the abrupt termination of the uplift in Cedar Mountain it would be postulated that the uplifted basement block is bounded by an east-west fault beneath the crest of that mountain. Such a fault would be rotatory about a horizontal axis and would not correspond to the strike fault which outcrops some distance farther south. What appears to be a continuation of the same uplift to the southeast is probably a second structure of similar type but of less magnitude. Sharp bends in the outcrops south of Cedar Mountain represent the adaptation of strata of varying resistance to the two adjacent displaced blocks beneath.

Fluctuations in the dip and local overturning of the beds along the west flank of Rattlesnake Mountain are comparable to similar conditions on the flanks of the Bighorn Mountain uplift. The development of such variations along the Colorado Front Range is sketched by Finlay.[16] It is doubtful if such changes along the front of an uplifted mountain range indicate any fundamental difference in structural conditions.

Pat O'Hara Mountain is nowhere sufficiently incised to reveal directly its deeper structure. The presence of a normal fault parallel to the axis of uplift, the thinning of the upturned strata, and the abrupt termination of the uplift on the east indicate that its structure is of the same type as Rattlesnake–Cedar Mountain. The number and attitude of displaced basement blocks underlying Pat O'Hara Mountain must be somewhat different to have produced a bowed rather than sharply flexed form of the Madison limestone over the crest (Fig. 1, Sec. 1).

[16] George I. Finlay, "Colorado Springs Folio," *U.S. Geol. Surv. Folio 203* (1916), Fig. 7.

Finally, what conclusions can be drawn as to the way in which the two uplifted structures intersect? Two indications that the structure of Pat O'Hara Mountain was developed, at least in part, after that of Rattlesnake Mountain are: (1) termination of the northeast dip slope against the Pat O'Hara fault, and (2) the presence of eastward dipping beds of Madison limestone west of Pat O'Hara Peak, which could be interpreted as an uplifted portion of those of Rattlesnake Mountain.

The normal fault structures of Rattlesnake and Pat O'Hara mountains are in many respects similar to fault blocks of the "plateau" or "basin-range" type. Gilbert[17] in his original description of the type shows in a series of cross sections of the Sevier fault, the lateral and vertical gradations of a normal fault into a sharp flexure and its branching into a group of sub-parallel faults. Many examples of the gradation of faults into flexures have been recognized and a number of geologists have discussed the relation of deep-seated faults to overlying structures. In particular, the monoclinal flexures and flat-topped uplifts in the Cretaceous of central Montana have been interpreted by Thom[18] as the result of faulted basement blocks. There the faulted blocks are merely interpreted from drill records and geophysical data, but in Shoshone Canyon the deeper portions of just such a structure are remarkably revealed by a relief of over 4,000 feet. Every stage from the upfaulted block of pre-Cambrian granite to the sharply flexed Carboniferous strata is exposed to observation. The final expression of the uplift in the higher Cretaceous formations is not shown in Rattlesnake Mountain; but, with this assurance of the correctness of Thom's interpretation, the "anticlines" of central Montana and of the Bighorn Basin are believed to be precisely this expression.

Flexures of the type so well exemplified in Rattlesnake Mountain have been variously named "incompetent folds," "plains-type folds," or "*unechte Falten.*" They possess certain characteristics which

[17] G. K. Gilbert, "Geology of a Portion of Nevada, Utah, California and Arizona," *U.S. Geol. Surv. west of 100th Mer.*, Vol. III (1875), p. 50, Fig. 25.

[18] W. T. Thom, Jr., "The Relation of Deep-seated Faults to Surface Structural Features in Central Montana," *Bull. Amer. Asso. Petr. Geol.*, Vol. VII (1923), pp. 1–13.

distinguish them from true folds of the Appalachian type, and indicate their similarity to monoclinal flexures. (1) Anticlinal flexures never occur as a wave-like succession of anticlines and synclines but as individual uplifts above the regional level of the strata. (2) Anticlinal flexures are usually distinctly asymmetric; or, if symmetrical with respect to the axial plane, show a flat top bordered by sharp flexures. (3) Normal faults parallel to the axes of flexures are abundant, whereas in competently folded regions normal faults are less conspicuous and more often transverse. (4) Thickening of strata does not occur, and thinning takes place near the axis of flexures rather than on the limbs. (5) The axial planes of asymmetric, incompetent folds tend to be vertical or dip toward, rather than away from, the steep limb.

Certain striking features of a large number of anticlines in the Bighorn Basin were noted by Hewett and Lupton.[19] With very few exceptions the anticlines occur in a zone bordering the Basin; each axis strikes roughly northwest; and each uplift is noticeably asymmetric in cross section. Furthermore, the asymmetry is consistently such that the flatter limb of the flexure is toward the center of the basin, whether that be northeast or southwest. Rattlesnake Mountain meets every condition for the largest of the border-zone anticlines. Many, if not all, of the other anticlines show features and associations characteristic of incompetent rather than competent folds. With definite knowledge of Rattlesnake Mountain, the writer would suggest that each anticline of the border-zone marks a displacement in the basement complex by uplift and tilting. Two reasons for the absence of anticlines in the center of the Bighorn Basin are (1) that uplifts were largely pre-Wasatch and are still covered by unconformable sediments, and (2) that small displacements in the basement complex would be completely absorbed by the greater thickness of soft or unconsolidated strata overlying.

Whatever may be the relationship of Rattlesnake Mountain to the Beartooth Range, it is certainly not one of simple continuity. A detailed study of the intervening Sunlight basin area may ultimately

[19] D. F. Hewett and C. T. Lupton, "Anticlines in the Southern Part of the Bighorn Basin, Wyoming," *U.S. Geol. Surv. Bull. 656* (1917), Pl. 1, p. 33.

indicate some connection between the two uplifts, and show that Rattlesnake and Pat O'Hara mountains are parts of the enclosing ranges rather than local uplifts within the Bighorn Basin.

Heart Mountain overthrust.—No new or conclusive evidence as to the direction, magnitude, or method of emplacement of the Heart Mountain overthrust was gained. Two bodies of limestone, however, one south and one west of Pat O'Hara Peak (Fig. 1; Fig. 7), when interpreted as remnants of the overthrust, give a definite measure of later displacement of the thrust plane. These two remnants are not shown on earlier maps of the overthrust. Their discordant strikes and dips, and excessive fracturing, however, suggest that they should be included. The limestone body south of Pat O'Hara Peak is preserved by its protected position on the down-throw side of the Pat O'Hara fault, whereas all traces of the overthrust have been removed from the higher ridge of Rattlesnake Mountain.

In order to interpret the geologic history of the region, and the relations to Rocky Mountain orogeny, one must accept a hypothesis for the development of the Heart Mountain overthrust. Since Hewett[20] suggested that the Heart Mountain overthrust rode forward over an even surface of erosion and aggradation, other conclusive examples of "erosion thrusts" have been described by Longwell, Hume,[21] and others. Moreover, it is believed that the Heart Mountain thrust belongs to the same phase of orogeny as the great zone of overthrusts which extends from southeastern Nevada to northern British Columbia. Even though Heart Mountain lies well to the east of this northerly trending zone, it is not thought necessary to invoke any singular cause of overthrusting such as that suggested by Bucher.[22]

Post-overthrust faulting.—Evidence of renewed uplift of Rattlesnake and Pat O'Hara mountains after overthrusting is not entirely conclusive. It offers, however, the simplest explanation of the height to which Rattlesnake Mountain rises above the overthrust on either

[20] *Jour. Geol.*, Vol. XXVIII (1920), p. 554.

[21] C. R. Longwell, "Structural Studies in Southern Nevada and Western Arizona," *Geol. Soc. Amer. Bull. 37* (1926), pp. 570–72; G. S. Hume, "Overthrusting in the Foothills of Alberta," *Econ. Geol.*, Vol. XXVI (1931), pp. 263–68.

[22] W. H. Bucher, "Volcanic Explosions and Overthrusts," *Trans. Amer. Geophys. Union for 1933*, pp. 238–42.

side. It accounts for the different levels of overthrust remnants north, west, and south of Pat O'Hara Mountain. Wasatch conglomerates appear to be down-dropped at the head of Rattlesnake Valley and the arkoses are cut by small transverse faults. Normal faults displacing the overthrust planes are conspicuous features of areas described by Mansfield and Hewett,[23] who interpret them as mid-Tertiary or "basin-range" in age. This age for the Rattlesnake Mountain displacements seems very plausible, since it would group them with the faulting which must necessarily have accompanied the intense Miocene vulcanism in the Absaroka Range. On the other hand, there is a suggestion that faulting has continued until recent time.

At the headwaters of Rattlesnake Creek, within an area of half a square mile (blank in Fig. 1), the soil is heaved and crumpled. Vertical displacements along approximately straight lines and the absence of any landslide scars suggest a direct tectonic disturbance. Moreover, in June, 1925, open fissures developed in the lower part of Rattlesnake Valley and an abandoned well near Cody depot suddenly gushed forth. What relation exists between these phenomena and displacements on the Rattlesnake and Pat O'Hara faults was not ascertained.

Types of Rocky Mountain structure.—Many geologists have recognized distinct types of structure in various parts of the Rocky Mountains. Chamberlin[24] refers to them as "thick-shell" and "thin-shell" types of mountains and suggests a distinction between the northern and the southern Rockies. Penck[25] elaborates the discussion further and rather overemphasizes the demarcation of the Rocky Mountains of Montana and Canada from those of Wyoming and Colorado. Thrust structures, to be sure, predominate over simple block uplifts in the Canadian and Montana Rockies, but through western Wyo-

[23] G. R. Mansfield, "Geography, Geology and Mineral Resources of Southeastern Idaho," *U.S. Geol. Surv. Prof. Paper 152* (1927); D. F. Hewett, "Geology and Ore Deposits of the Goodsprings Quadrangle, Nevada," *U.S. Geol. Surv. Prof. Paper 162* (1931).

[24] R. T. Chamberlin, "The Building of the Colorado Rockies," *Jour. Geol.*, Vol. XXVII (1919), p. 251.

[25] A. Penck, "Geomorphologische Probleme in ferner Westen Nordamerika," *Sitzber. Preus. Akad. Wissen.* (1929), *Math.-Phys. Kl.*, pp. 207–9.

ming, eastern Idaho, and Nevada is a zone of overthrusts of scarcely less magnitude. Kober[26] takes cognizance of the continuity of the zone of overthrusts in developing his schematic picture of orogeny of North America. Finally, Billingsley[27] makes a sharp distinction between the "overthrust arc" and the "folded zone" of the Rocky Mountains.

The writer also believes it more objective to divide the Rocky Mountain structures into longitudinal zones rather than a northern and a southern type; but he would not go so far as to deduce the symmetrical orogenic plan of Kober, nor would he make such broad interpretations as does Billingsley.

It has frequently been noted that there is a progressive thickening of the Paleozoic strata from east to west in any section across the Cordilleras. The important fact from a structural point of view is that within the zone of large overthrusts the pre-Cretaceous strata are, with few exceptions, over 7,500 feet thick. In the eastern region of uplifted ranges the corresponding column is incomplete and rarely more than 2,000 feet thick. The Paleozoic series in Montana is less thick, but the Algonkian Belt series plays an equivalent rôle in the overthrusting. A relation between thick series of geosynclinal sediments and intensive compressional deformation has been recognized by nearly all students of orogenesis. The writer merely wishes to emphasize the widespread application of this association in the Cordilleran region. What were the fundamental determining factors for the two types of Rocky Mountain structure is entirely conjectural.

This somewhat extended discussion of the two major zones of Rocky Mountain orogeny is justified by the fact that within a small area in northwest Wyoming the two overlap. The greatest extent of overlap would be from the overthrust on Heart Mountain to the uplift of the Teton Range. Evidence of the distinct ages of the two types of deformation has been found in the Shoshone Canyon region. Hewett[28] concluded, from the age of the latest overridden sediments and the oldest overlying volcanics, that overthrusting was during

[26] L. Kober, *Der Bau der Erde*, 2d ed. (1928), pp. 316–21.

[27] Paul Billingsley, "Geologic History and Geologic Structure of the Salt Lake Region," *XVI Int. Geol. Cong. Guidebook 17* (1933), pp. 19–24.

[28] *Op. cit.*, p. 555.

late Eocene. It has been shown that the uplift and beveling of the Rattlesnake Mountain structure was not merely pre-overthrust but also pre-Wasatch. Materials in the Wasatch, unmistakably derived from the pre-Cambrian complex, indicate that great uplifts to the west and north had risen and been deeply eroded before the Eocene. One of these uplifts was the Beartooth Range against which the later Heart Mountain overthrust probably impinged. The age of the Bighorn Mountain or Owl Creek Mountain uplifts is not determined. The Laramie and Colorado Front Ranges are usually interpreted as late Cretaceous, and one might believe that all the larger pre-Cambrian blocks had started to rise before Wasatch time.

There may be represented in western Wyoming yet a third phase of Cordilleran orogeny which is typified by basin range structure, i.e., mid-Tertiary normal faulting. Whereas in Nevada and Utah these faults formed fresh breaks across both folded and overthrust structures, in the Shoshone Canyon area they resulted in renewed movement along the pre-Eocene fault planes of the underlying basement.

GEOLOGIC HISTORY

A few traces of the earliest recorded stage of the geologic history of the region are preserved in the lenses of hornblende-schist of the pre-Cambrian complex. Early pre-Cambrian sediments, which are more extensively preserved in neighboring areas, have been altered to schist and para-gneiss during a period of orogeny. This was followed by intrusion of large bodies of granitic rock together with more basic intrusives. Joints developed during this intrusion were filled without interval by pegmatites. At a distinctly later period in the pre-Cambrian, basaltic dikes intruded all the older complex throughout the region. A long cycle of erosion, in late pre-Cambrian and early Cambrian time, produced a nearly plane surface across all of the early rocks. This surface is everywhere irregularly uplifted or tilted but is rarely seen to be sharply folded or warped by later orogeny.

The sea advanced over this erosion surface in the middle Cambrian, receded in the early Ordovician, and readvanced to greater depth in late Ordovician time. Before the end of the Silurian the region was raised above sea level so that channels were eroded and later filled by Devonian sediments. The slight sedimentation during the

Devonian was followed by uniform marine conditions in Mississippian time. In the Pennsylvanian, frequently changing conditions of sedimentation produced a series of limestones, shales, cherts, and cross-bedded sandstones. Continental and peculiar shallow-water conditions prevailed through the Permian and Triassic. Following a brief emergence in the early Jurassic, normal shallow marine conditions continued through late Jurassic, early Cretaceous, and a large part of late Cretaceous time.

Although evidence exists that regions to the west and north were subject to orogenic disturbances as early as the Jurassic, the first uplift of the Rattlesnake Mountain structure is believed to have taken place very late in the Cretaceous. Eocene erosion truncated the late Cretaceous uplifts, cutting down to the Carboniferous limestone on Rattlesnake Mountain and to the pre-Cambrian granite in the mountains which had risen farther to the northwest. Subsidence of the Bighorn basin continued through the Eocene and large amounts of material were transferred from the elevated regions of Paleozoic and pre-Cambrian exposures to the Basin, where they were deposited as Wasatch arkoses and clays on top of the thick Cretaceous sedimentary series. Rattlesnake Mountain lay at the border of the basin of deposition where a small thickness of coarse material was deposited along stream channels.

Upon the Wasatch surface, made even by erosion and aggradation, the great mass of Paleozoic limestones of the Heart Mountain overthrust plate moved forward. New lines of drainage established themselves upon the surface of the overthrust plate. During the Oligocene and early Miocene these rivers removed a large part of the fractured limestone of the upper block and had begun to incise the underlying surface, developed in the early Eocene. The major streams maintained the courses which they developed on top of the thrust block and cut indiscriminately into the underlying structures. Thus, Shoshone River in the Shoshone Canyon is clearly superimposed upon the Cedar–Rattlesnake Mountain uplift. Another definite example of a superimposed stream within the Heart Mountain overthrust zone is Ox Yoke Canyon of Pat O'Hara Creek.

Following the overthrusting and possibly continuing to Recent times there has been further differential elevation of the Rattlesnake

Mountain and Pat O'Hara Mountain blocks by renewed movement along the pre-Eocene lines of faulting. On the basis of the present positions of remnants of overthrust limestone and of Wasatch conglomerate, the renewed uplift of Rattlesnake Mountain is estimated to be 1,200–2,000 feet. The west end of Pat O'Hara Mountain and the South end of Rattlesnake Mountain were the most elevated. Consequently there is a differential uplift of 800–1,600 feet of Pat O'Hara Mountain above the north end of Rattlesnake Mountain. During this uplifting, Shoshone River maintained its course as an antecedent stream.

By late Miocene most of the overthrust plate had been removed when great quantities of "early basic breccia" were ejected to form a new mountain range of the Absarokas. Volcanics are found at an elevation of 7,500 feet in Rattlesnake Valley and at 10,100 feet on Pat O'Hara Peak. Probably they once covered much of Rattlesnake and Pat O'Hara mountains and a large part of the soft Cretaceous and Eocene beds south and west of Cedar Mountain, but there is some doubt whether the site of Shoshone Canyon was under lava cover.

Since the Pliocene, erosion has dissected the lava plateau of the Absarokas as rapidly as the stream gradient has been renewed by the cutting of Shoshone Canyon. Where soft Cretaceous and Tertiary beds were unprotected or capped by only a thin layer of lavas or overthrust limestones, broad valleys were opened out. Especially to the south of Cedar Mountain a broad plain has been eroded and two streams flowing into the Shoshone River above and below the Canyon, respectively, are separated by a very low divide. Rattlesnake Creek and Trail Creek developed as subsequent streams along the strike of the softer strata and help to emphasize the topographic expression of the Rattlesnake Mountain uplift.

Rock benches and terraces indicate the later stages of development of Shoshone Canyon, but neither moraines nor glacial outwash are found in the immediate vicinity. The oldest feature is a bench on either side of the canyon, 1,000 feet above the present stream. It is not developed directly upon the surface of the resistant pre-Cambrian granite, but 300–500 feet stratigraphically above it, indicating a broad valley developed at a determined elevation without regard

for rock hardness. Correspondence in elevation with the broad, outer valley of Clark Fork is very close. That level is considered by Alden[29] to be the mountainward projection of the Flaxville plain of Pliocene age.

Upon the Flaxville surface, before its dissection, there are, in a few Montana localities, remnants of early Pleistocene moraines. During the Pleistocene but before Wisconsin time, there were two more stages of river entrenchment and valley broadening. The first of these is represented east and south of Shoshone Canyon by broad gravel terraces 200–300 feet above the present streams. This level skirts the base of Carter Mountain and extends down both sides of Shoshone River above the town and station of Cody. Gravel-capped hills west of Sulphur Creek are believed to belong to this stage, since the level at which the smaller creeks are now flowing corresponds to the next younger terrace of the river. The innermost river terraces, 100–150 feet above stream level, are shown by Alden to underlie the Wisconsin moraines. Irma Flat, southeast of Shoshone Reservoir, and the terrace on which the town of Cody is located represent this stage. In Recent times the Shoshone has entrenched itself in the underlying bed rock east of the canyon and has continued to deepen its gorge through the granite core of Rattlesnake Mountain. Entrenchment of the late Pleistocene terrace is proceeding headward along all of the tributary streams with the exception of Rattlesnake and Diamond creeks where normal development has been halted by the artificial water level of Shoshone Reservoir.

[29] W. C. Alden, "Physiography and Glacial Geology of Eastern Montana and Adjacent Areas," *U.S. Geol. Surv. Prof. Paper 174* (1932), p. 27.